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14. ABSTRACT
Temporal and spatial variability of Sea Surface Temperature (SST) and ocean colour in the Japan/East Sea (JES) are examined during winter and spring using satellite data from Advanced Very High Resolution Radiometer (AVHRR) and Sea-viewing Wide Field of view Sensor (SeaWiFS). The timing of the spring phytoplankton bloom and the locations of the chlorophyll fronts are related to changes in the thermal fields and the locations of the temperature fronts. Daily images of SST and chlorophyll concentration show both differences and similarities of bio-optical and thermal front location, depending on region and season. Four sub-regions in the JES were defined and SST and chlorophyll values were extracted from weekly and monthly composite images to derive summary statistics. SST at the Subpolar Front increased about 70C over a 1.5- month period from late April to early June in 1999. During this same period, elevated chlorophyll values near the Korean coast and in the southern basin decreased sharply as the phytoplankton bloom that first developed in the southern basin progressed to the front and northward. The SST/chlorophyll relationship is complex and seasonal. Near the Subpolar Front, SST and chlorophyll were positively related in April. In May, highest chlorophyll values corresponded to mixing regime by June. SST and chlorophyll near the front were inversely related.

15. SUBJECT TERMS
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Temporal and spatial variability of satellite sea surface temperature and ocean colour in the Japan/East Sea

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Abstract. Temporal and spatial variability of Sea Surface Temperature (SST) and ocean colour in the Japan/East Sea (JES) are examined during winter and spring using satellite data from Advanced Very High Resolution Radiometer (AVHRR) and Sea-viewing Wide Field of view Sensor (SeaWiFS). The timing of the spring phytoplankton bloom and the locations of the chlorophyll fronts are related to changes in the thermal fields and the locations of the temperature fronts. Daily images of SST and chlorophyll concentration show both differences and similarities of bio-optical and thermal front location, depending on region and season. Four sub-regions in the JES were defined and SST and chlorophyll values were extracted from weekly and monthly composite images to derive summary statistics. SST at the Subpolar Front increased about 7°C over a 1.5-month period from late April to early June in 1999. During this same period, elevated chlorophyll values near the Korean coast and in the southern basin decreased sharply as the phytoplankton bloom that first developed in the southern basin progressed to the front and northward. The SST/chlorophyll relationship is complex and seasonal. Near the Subpolar Front, SST and chlorophyll were positively related in April. In May, highest chlorophyll values corresponded to mixing regimes (such as areas of convergence and divergence at the edges of meanders) and, by June, SST and chlorophyll near the front were inversely related.

1. Introduction

The Japan/East Sea (JES) is a semi-enclosed basin with restricted inflow and outflow and complex internal circulation. The northern Japan Basin is generally 2500–3700 m deep, whereas the southern basin is shallower with more complex bottom topography. During the winter, dry, cold-air outbreaks sweep off Siberia and cause rapid cooling of the surface waters, resulting in convective overturning of the upper layers (Kawamura and Wu 1998). In the spring, the water column stratifies and a phytoplankton bloom develops.

Warm, oligotrophic water enters the basin from the south through the Tsushima/Korea Strait and bifurcates into the Tsushima Warm Current (TWC) that flows eastward along the northern coast of Japan and the East Korean Warm Current (EKWC) that flows northward along the Korean Peninsula (Hirose and

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Ostrovskii 2000). A third branch through the central southern basin may also be present. The EKWC separates from the Korean coast near 37° N and meanders eastward, bisecting the basin and forming the Subpolar Front around 40° N (figure 1). The front separates the cold, dense, weakly stratified northern water from the warmer, stratified water to the south. The Subpolar Front is a region of very active eddy formation (Takematsu *et al.* 1999) and exhibits strong thermal and bio-optical gradients. Flow exits the basin to the north, through the Tsugaru and Soya Straits (figure 1; Soya Straits are located off the figure, at 45.5° N, 142° E).

The objective of this research is to characterize and interpret the spatial and temporal variability of SST and chlorophyll in the JES, by coupling Advanced Very High Resolution Radiometer (AVHRR) and Sea-viewing Wide Field of view Sensor (SeaWiFS) imagery. By comparing individual SST and chlorophyll images collected at nearly the same time, one can begin to assess whether thermal and bio-optical fronts are spatially co-located. Specifically, this paper compares locations of thermal and bio-optical fronts in satellite imagery; examines SST and chlorophyll variability at the Subpolar Front; describes the timing and spatial distribution of the spring bloom in the JES; and describes regional variability in chlorophyll concentration, by month.

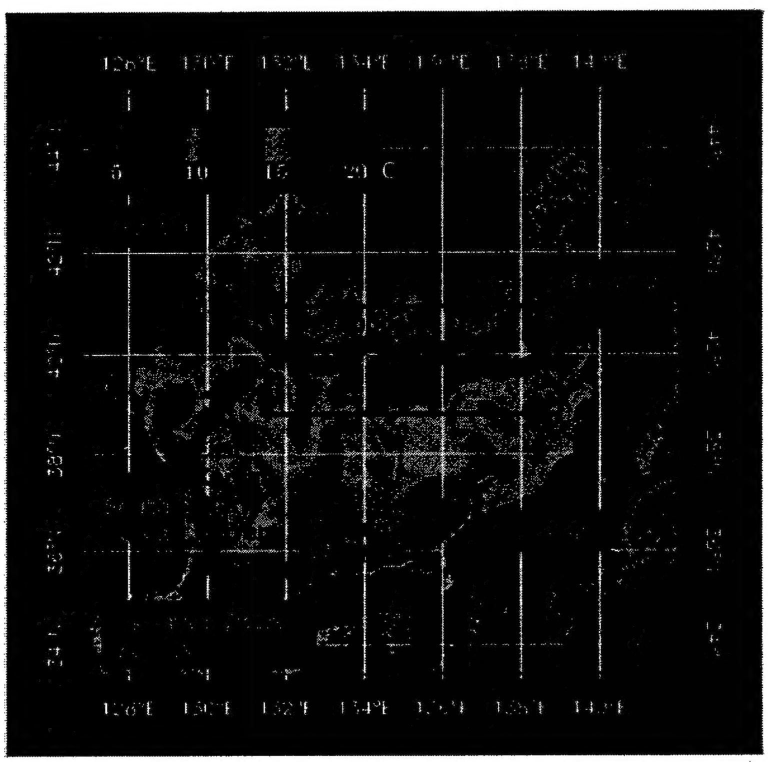

Figure 1. AVHRR SST image (collected 20 May 1999) of the JES region, with major currents, straits and circulation features highlighted. The temperature scale is indicated in the figure. The red box outlining the region of the Subpolar Front denotes the area of coverage of the sub-sectioned images in figure 2.

2. Methods

A two-year climatology of daily AVHRR (SST) and SeaWiFS (bio-optics) imagery of the JES at 1 km spatial resolution has been compiled. Some of the imagery was collected at sea during two cruises to the region (May/June 1999 and January/February 2000), using a shipboard receiving system. The real-time satellite thermal and ocean colour imagery enabled optimization of station locations and cruise tracks, provided the large-scale context of the circulation and a broader context to aid interpretation of cruise data (shipboard data will be presented elsewhere). In addition, archived imagery was obtained from NASA/Goddard Distributed Active Archive Center, NOAA Satellite Active Archive Center and Dr Ichio Asanumai at Japan Marine Science and Technology Center (JAMSTEC). The imagery provides a long-term time series to characterize the spatial and temporal variability of the region. Products from the SeaWiFS imagery include chlorophyll concentration and absorption and backscattering coefficients at six wavelengths (Arnone and Gould 1998), but only chlorophyll imagery is presented here. In addition to daily imagery, weekly and monthly composites have been created to reduce cloud-contaminated pixels. SeaWiFS imagery was processed using a modified version of SeaDAS (version 3.3) and the SeaBAM (OC2) chlorophyll algorithm.

3. Results

To assess the relationship between SST and chlorophyll fronts, three AVHRR and SeaWiFS scenes were selected covering the region of the Subpolar Front, during the period of the spring bloom, to examine patterns during a transition period. The AVHRR and SeaWiFS passes selected for analysis were nearly coincident in time (collected within 3–8 hours of each other), relatively cloud-free and representative of the three-month period from April to June 1999. Figure 2 (left panel) shows the SST imagery with high-chlorophyll pixels from the corresponding SeaWiFS images overlain in magenta (magenta pixels represent chlorophyll values $\geqslant 2.0\,\mu g\,l^{-1}$ for the top and middle images, and $\geqslant 0.75\,\mu g\,l^{-1}$ for the bottom image). The chlorophyll thresholds for these images are arbitrary but were selected after examination of temperature vs. chlorophyll scatter plots, to facilitate the spatial/temporal comparisons. SST and chlorophyll values extracted along an image transect are also plotted in figure 2 (right panel), to show the spatial coherence of the thermal and bio-optical fields. SST at the Subpolar Front increased about 7°C over a 1.5-month period from late April to early June in 1999. During the same period, chlorophyll concentrations decreased from maximum values of $>30\mu g\,l^{-1}$ in April to $10\,\mu g\,l^{-1}$ in May and $1\,\mu g\,l^{-1}$ in June. These chlorophyll values seem somewhat high and may be related to remaining problems with the atmospheric correction of the imagery. In April, highest chlorophyll values were located south of the Subpolar Front and were positively related to SST. In May, highest chlorophyll values were located just north of the front and in areas of strong mixing south of the front, such as in the bends of meanders. By June, highest chlorophyll concentrations were located north of the front in the colder waters and showed an inverse relationship with SST.

To examine the regional chlorophyll and SST variability over a nine-month period (January–August 1999), the JES was divided into four sub-regions: the Northern Basin, the Subpolar Front, the Southern Basin and the South Korean Coast. For each region the chlorophyll concentration and SST were extracted from

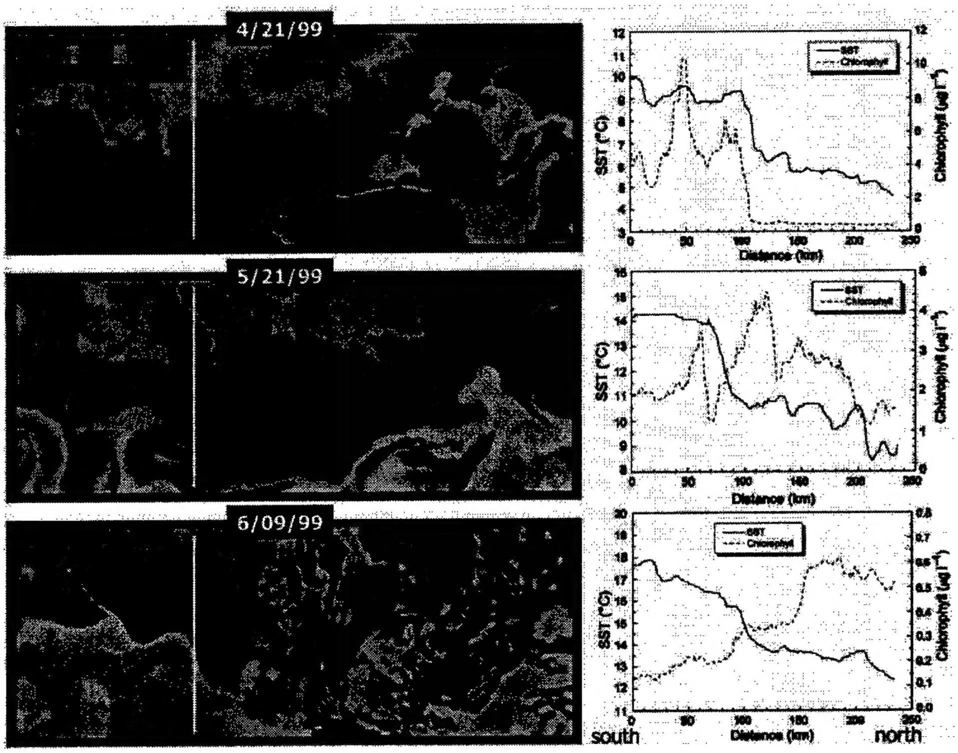

Figure 2. Spatial and temporal variability of SST and chlorophyll at the Subpolar Front. Left panel: AVHRR SST imagery collected 21 April 1999, 21 May 1999 and 9 June 1999. Highlighted (magenta) pixels indicate areas of highest chlorophyll from SeaWiFS (greater than $2.0\,\mu g\,l^{-1}$ in top and middle images; greater than $0.75\,\mu g\,l^{-1}$ in bottom image). The images cover the area denoted by the red box in figure 1. Right panel: AVHRR SST and SeaWiFS chlorophyll values extracted along the vertical transect in each image in the left panel (represented by the white lines).

the SeaWiFS and AVHRR monthly composite images and regional, monthly averages were calculated (figure 3). The spring phytoplankton bloom started in March in the southern basin and progressed northward. At the Korean Coast, South Basin and Subpolar Front, chlorophyll values peaked in March and decreased through June, with a sharp decrease between April and May in the South Basin. The highest mean chlorophyll concentrations were observed in the South Basin in March. In the North Basin, chlorophyll values remained low through April, peaked briefly in May and decreased by June; the June values in the North Basin were higher than in the other three regions, however. Temperatures varied widely from region to region in the January–March time period, with highest temperatures observed in the Korean Coastal region. In January, the mean SST in the Korean Coastal region was 11.4°C higher than in the North Basin region, which was the coldest. SST increased slightly in the Korean Coastal and Southern Basin regions by March and in all regions by April. Thus, the peak in chlorophyll concentration slightly preceded the maximum thermal gradient. By August, the surface waters of the JES were nearly isothermal, with just a 2.8°C difference between mean SST values in any of the regions.

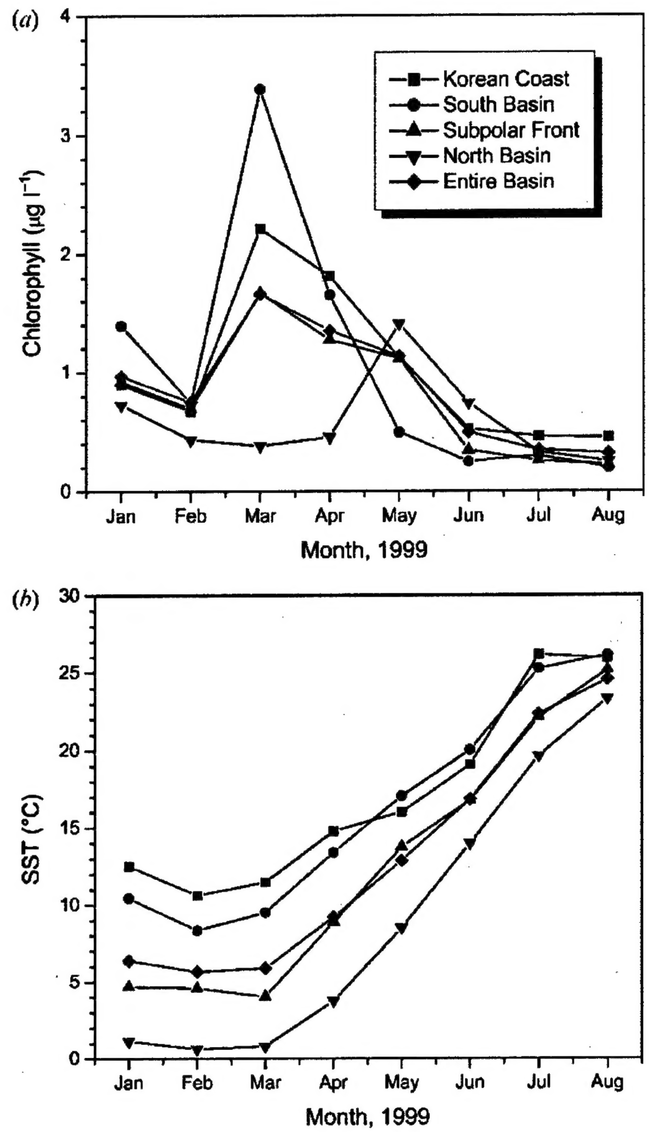

Figure 3. (*a*) Mean SeaWiFS chlorophyll concentrations in the JES, by region and month, from January to August 1999. (*b*) Mean SST in the JES, by region and month, from January to August 1999.

4. Summary

The JES is a dynamic region dominated hydrographically by the Subpolar Front, eddy activity and winter-time convective overturning. The SST/chlorophyll relationship is complex, with regional and temporal dependencies. At the Subpolar Front, during the April–June time period, strong spatial correlation was observed between SST and chlorophyll concentration. SST and chlorophyll were positively related in April, with high chlorophyll associated with the warm waters south of the front. By June, they were inversely related, with highest chlorophyll values associated with the cooler waters north of the front. The spring phytoplankton bloom started in late March–early April in the southern basin and progressed

northward through late May, ending in all areas by early June. Regionally, in the January–August 1999 time period, the mean chlorophyll concentration was highest at the Korean Coast, South Basin and Subpolar Front in March; in the North Basin, it was highest in May. Results suggest that SST and chlorophyll ocean features are not always coincident and that seasonal influence must be considered when interpreting the imagery.

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